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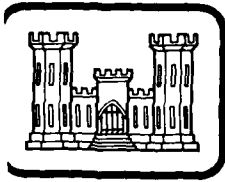   JAN 81   D R RICHARDS, S R RIVES, D F BASTIAN
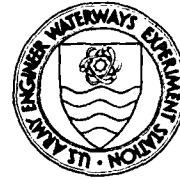UNCLASSIFIED   WES/MP/HL-81-2   NL

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NANTICOKE RIVER, MARYLAND
DYE DISPERSION STUDY

Chesapeake Bay Hydraulic Model Investigation

by

David R. Richards, Stephen R. Rives, David F. Bastian

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

January 1981

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for U. S. Army Engineer District, Baltimore
Baltimore, Maryland 21203

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REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER Miscellaneous Paper HL-81-2	2. GOVT ACCESSION NO. AD-AC95 895	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) NANTICOKE RIVER, MARYLAND, DYE DISPERSION STUDY; Chesapeake Bay Hydraulic Model Investigation,	5. TYPE OF REPORT & PERIOD COVERED Final report.	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) David R. Richards Stephen R. Rives David F. Bastian	8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Hydraulics Laboratory P. O. Box 631, Vicksburg, Miss. 39180	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Engineer District, Baltimore P. O. Box 1715 Baltimore, Md. 21203	12. REPORT DATE January 1981	
	13. NUMBER OF PAGES 27	
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Chemical wastes
Dye dispersion
Hydraulic models
Nanticoke River
Pollutants

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The potential for a hazardous chemical leak into the Nanticoke River
from a chemical storage facility at Sharptown, Maryland, prompted the State of
Maryland to request a study to assess the movement of waterborne contaminants
in the Nanticoke River. Thus a test was conducted to monitor the movement of a
dye tracer in the existing physical model of Chesapeake Bay.

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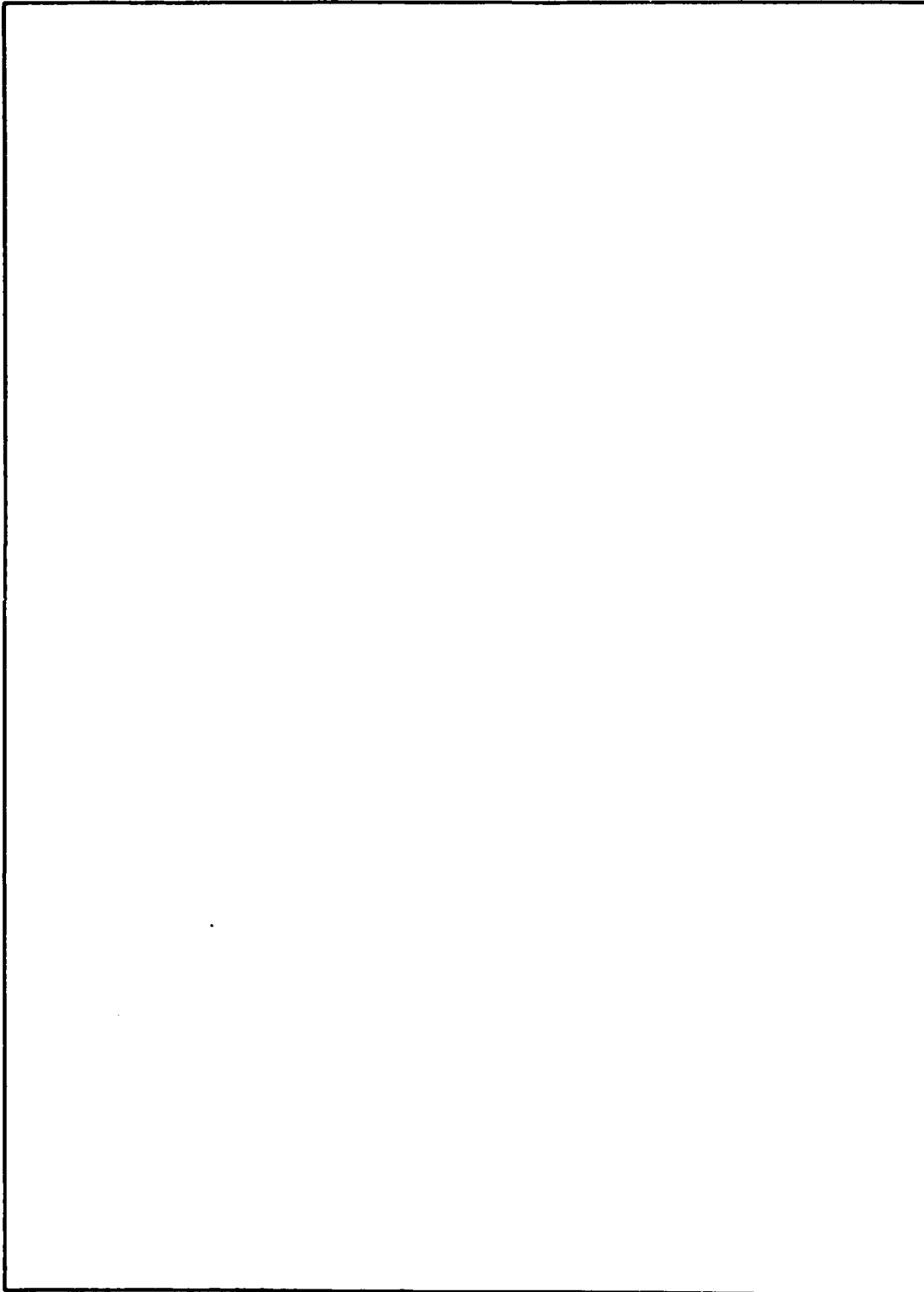
PREFACE

A request for the U. S. Army Engineer Waterways Experiment Station
(WES) to conduct a hydraulic model investigation was made by the U. S.
Army Engineer District, Baltimore (NAB), at the request of the State of
Maryland in October 1979. Funding for the study was provided by the
State of Maryland and all results were provided to the State within
two weeks of the request for the study.

The study was undertaken by the Chesapeake Bay Model Branch,
Estuaries Division, Hydraulics Laboratory, WES, under the direction
of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory; F. A.
Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory; R. A. Sager,
Chief of the Estuaries Division; and D. F. Bastian, Chief of the Chesa-
peake Bay Model Branch. Project Engineer was Mr. D. R. Richards. The
actual tests were conducted by members of the staff of Acres American,
Inc. (contractor to WES for operation of the Chesapeake Bay Model) under
the direction of Dr. J. W. Hayden. Mr. S. R. Rives was Project En-
gineer for Acres American, Inc. This report was prepared by Messrs.
Richards and Bastian of WES, and Mr. Rives of Acres American, Inc.

Commander and Director of WES during the conduct of this study and
the preparation and publication of this report was COL Nelson P. Conover,
CE. Technical Director was Mr. F. R. Brown.

1

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4047.0	square metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
gallons (U. S. liquid)	3.785412	cubic decimetres
miles (U. S. statute)	1.609344	kilometres
square miles (U. S. statute)	2.589988	square kilometres

NANTICOKE RIVER, MARYLAND, DYE DISPERSION STUDY

Chesapeake Bay Hydraulic Model Investigation

PART I: INTRODUCTION

Problem

1. On the west bank of the Nanticoke River at Sharptown, Maryland
(Figure 1), there are approximately 30 chemical storage tanks containing
roughly 170,000 gallons* of various toxic chemicals and industrial sol-
vents. A rupture of one or more of these tanks could seriously endanger
the river biota and adversely affect the people living nearby.

Prototype

2. Sharptown, Maryland, is about 31 miles upstream from the mouth
of the Nanticoke River. The 40-mile-long tidal portion of the Nanticoke
River drains a 700-square-mile watershed with an annual average discharge
of 841 cfs into Tangier Sound. The maximum depth of the Nanticoke is
50 ft. A 12-ft-deep by 100-ft-wide channel is maintained from mile 8 up-
stream to mile 40 at Seaford, Delaware. The artificially maintained por-
tions of the channel cover only 4 miles. A 6-ft-deep by 60-ft-wide (at
mean low water) channel is maintained in the Northwest Fork (Marshyhope
Creek) from 12 miles above its confluence with the Nanticoke up to mile
16 near Federalsburg, Maryland.**

3. The range of tide† varies from the mouth of the river to
Sharptown as follows:

Spring Tide Range, ft			Mean Tide Range, ft		
Mouth	Vienna	Sharptown	Mouth	Vienna	Sharptown
2.8	2.6	3.0	2.3	2.2	2.5

The respective mean low-water, intertidal, and mean high-water volumes for the Nanticoke River are 6.7, 1.9, and 8.6×10^9 cu ft.[*]

Objective

4. Specifically, the question addressed by the hydraulic model test was: What is the geographical extent of the "worst case" effects from a hypothetical release of a toxic substance at Sharptown?

5. The term "worst case" is ambiguous. It is not clear, for example, that a large lateral spread of relatively low-contaminant concentrations is better or worse than a confined spread of high concentrations. This que ʼon was discussed at a meeting on 19 October 1979 that was attended by personnel from the State of Maryland, Department of Natural Resources, Water Resources Administration (WRA), the U. S. Army Engineer District, Baltimore (NAB), the Chesapeake Bay Model Branch of the U. S. Army Engineer Waterways Experiment Station (WES), and Acres American, Inc. At that time, WRA expressed a preference for a model simulation of a more highly concentrated, more localized contaminant release, and the experiment was designed accordingly.

Scope

6. The study consisted of defining the temporal and spatial distribution of a neutrally buoyant conservative contaminant in the Nanticoke River representative of an accidental chemical release at Sharptown. A fluorescent dye was used as the tracer material.

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* William B. Cronin. 1971 (Mar). "Volumetric, Areal and Tidal Statistics of the Chesapeake Bay Estuary and Its Tributaries," Special Report 20, p 44, Chesapeake Bay Institute.

PART II: THE MODEL

Description

7. The Chesapeake Bay model reproduced the entire prototype estuary from Cape Henry and Cape Charles at its extreme southern end to the Chesapeake and Delaware Canal (C&D Canal) and the tidal Susquehanna River at its extreme northern end. The model also reproduced the major tributaries and numerous small tributaries to their respective heads of tide.

8. The physical model, located at Matapeake, Maryland, is of the fixed-bed type, molded entirely of concrete, and is constructed to linear scale ratios of 1:1000 horizontally and 1:100 vertically. These dimensions and Froudian model laws defined the following model-to-prototype ratios: velocity 1:10; time 1:100; discharge 1:1,000,000; volume 1:100,000,000. The salinity ratio is 1:1.

9. The model (see Figure 2), covering approximately 8 acres, includes topographical features of the prototype to the +20 ft msl contour. At the time of this study, all major ship channels were molded with the proposed 50-ft channels leading into Baltimore and the existing channels elsewhere.

Appurtenances

10. The model was equipped with the necessary appurtenances to reproduce and measure all pertinent phenomena. The appurtenances include primary and secondary tide generators, tide recorders, freshwater inflow devices, skimming weirs, salinity meters and vacuum system, current velocity meters, tide gages, and fluorometers for dye concentration determination.

Current meters

11. Current velocity measurements were made with miniature Price-type meters. The center line of the model cups on the meter was about 0.05 ft above the bottom of the meter frame. The overall width of the

meter was about 0.1 ft in the model, representing a horizontal width of about 100 ft in the prototype. Therefore, the distortion of area (model to prototype) resulted in model velocities averaged over a much larger area than those of the prototype point observations. The same was true for the vertical area since the height of the cups on the meter was equivalent to about 4.0 ft prototype. Velocities were obtained by counting the number of revolutions the meter made in a 10-sec interval (model) which was equivalent to about 17 min in the prototype. The meters were calibrated frequently to ensure the accuracy of measurements and were capable of measuring actual velocities as low as about 0.03 fps (0.3 fps prototype).

Point gages

12. Permanently mounted point gages were installed on the model at locations corresponding to the prototype recording tide gage locations at which verification tide data were collected, plus additional locations considered necessary for test purposes. These gages, graduated to 0.001 ft (0.1 ft prototype), measured tidal elevations.

Dye/salinity sampling apparatus

13. The sampling system consisted of a centrally located vacuum pump and reservoir with polyethylene tubing running from it to each of the sampling stations. Each station was independently valved so that select stations could be sampled, leaving others idle. A main valve at the vacuum reservoir activated the system, drawing up the water samples into 10-cc test tubes. The test tubes were collected after filling and placed in a water bath to bring the samples to room temperature for dye and salinity measurement.

Fluorometer

14. The concentrations of fluorescent dye were measured with a Turner fluorometer. The meters were calibrated to read values between 1 and 10,000 parts per billion (ppb). Accuracy of the fluorometer was about +3 percent for the range of concentrations measured.

PART III: MODEL TESTS AND RESULTS

Description of Test and Procedures

15. The condition of the Chesapeake Bay and the Nanticoke River
at the time of the chemical spill would determine, to a large extent,
the dispersion of contaminants in the system. Since this condition can
vary considerably and is unpredictable, a moderate approach to prototype
simulation was taken. To achieve this result, annual average freshwater
inflows and a slightly less than mean-ranged repeatable ocean cosine
tide were used. Boundary conditions for the test are shown in Table 1.

16. The ocean tide operated on a cosine cam set for an M2 tidal
frequency with a high water of 1.3 ft and a low water of -1.5 ft. This
resulted in a 1.9-ft tidal range at Vienna (sta N-30, see Figure 1)
which is slightly less than the average range of 2.4 ft reported in the
tide tables.

17. Freshwater inflows into the Nanticoke were confined to the
upstream limits of the model at three locations, i.e. Seaford, Delaware,
Gals Branch, Maryland, and Quantico Creek. The desired flows were
49, 25, and 19 cfs, respectively. The source salinity was maintained
at 32.5 ppt total salt throughout the test, and the model was operated
until salinity stability had been achieved prior to initiating the dye
release. The dye release point was at sta N-4 (Sharptown, Figure 1),
and 5.5 ml of Rodamine WT dye solution (approximately 2 ppm) was injec-
ted at the time of slack before flood of the first tidal cycle of the
dye test. The dye was injected at middepth over a short period.

Sampling Procedure

18. Sampling stations were located throughout the Nanticoke River
area (see Figure 1). Real time analyses were performed on several sta-
tions to determine the movement of the dye. In this way, additional
mobile sampling stations could be added if they were needed.

19. For stations where the prototype depth was between 30 and
40 ft, three samples were taken in the vertical (surface, middepth, and

9

bottom). Where the depth was between 10 and 20 ft, surface and bottom samples were taken; and for depths less than 10 ft, a single middepth sample was taken. Table 2 lists the sampling stations, their prototype depths, and the corresponding sampling depths.

20. Sampling started at the second slack before ebb after the dye injection and was continued at prescribed slacks for 58 tidal cycles (see Table 3). Slack water was considered synoptic about sta N-3A (Vienna). Hourly samples were taken at sta N-3A and N-3B during tide 13 so that the concentration distribution through one tidal cycle could be determined (see Table 4). Approximately 700 samples were taken during the test. The samples were collected by vacuum aspiration and taken to a temperature-controlled room where fluorometer readings were taken for each.

21. Tidal elevations and tidal current measurements were made at sta N-3A and N-3, respectively, before and after the test. The initial tidal elevation measurements had to be discounted due to an operator error, but the post-test measurements are considered accurate. Figure 3 is a plot of measured tidal elevations. Figure 4 shows the tidal currents.

Dye Scaling

22. There is significant variation among different lots of Rhodamine WT base solution as it is received from the manufacturer. Similar dilutions of a similar quantity from two different lots will, in general, yield different fluorescence values on a fluorometer. To avoid this problem, the fluorometer was calibrated in terms of C/C_s, where C is the concentration of dye in a sample and C_s is the concentration of dye in the base solution.

23. Letting m_d be the mass of pure (dry) Rhodamine WT in a given sample; M, the mass of that sample; M_s, the mass of base Rhodamine WT solution that contains m_d of pure dye; the concentration of Rhodamine WT in a sample is then m_d/m and the concentration, C_s, of dye in the base solution is m_d/M_s. Therefore,

$$\frac{C}{G} = \frac{M_s}{M} \qquad (1)$$

24. By carefully diluting the base solution with distilled water, samples of known C/G can be constructed. These samples were then used to calibrate the fluorometer. It is necessary during the initial dilutions to take into account the specific gravity of the base solution if dilution is being made by volume.

25. By the definition of G

$$\frac{C}{G} = \frac{C}{\left(\dfrac{m_d}{M_s}\right)_{inj}} \qquad (2)$$

where the subscript "inj" refers to the pure dye and base solution injected into the model during the test. Dividing this equation by $\left(M_s\right)_{inj}$ yields

$$\frac{C}{G\left(M_s\right)_{inj}} = \frac{C}{\left(m_d\right)_{inj}} \qquad (3)$$

26. For the Sharptown test, 5.9 ml of dye solution ($C/G = 9.985 \cdot 10^{-3}$) was injected. At this dilution, specific gravity is essentially unity (cgs units) and

$$\left(M_s\right)_{inj} = 5.9 \text{ ml} \times \frac{1 \text{ gram}}{\text{ml}} \times 9.985 \times 10^{-3} \frac{\text{grams base solution}}{\text{grams of sample}} \qquad (4)$$

27. The fluorometer was calibrated in terms of C/G and a least-squares linear fit to the calibration data yielded,

$$\frac{C}{G} = 4.878 \times 10^{-9} \times \text{(fluorometer dial readings)} \qquad (5)$$

and therefore

$$\frac{C}{G\left(M_s\right)_{inj}} = \frac{C}{\left(m_d\right)_{inj}} = 8.280 \times 10^{-8} \times \text{(fluorometer dial reading)} \qquad (6)$$

10

28. All fluorescence values were scaled to C/m_d (parts per billion per gram of pure dye injected) by the above equation. Tables 3 and 4 list the values of C/m_d for the slack-water samples and hourly samples, respectively. These values can be interpreted as the concentrations in ppb that would result from the injection of one gram of pure dye under similar model conditions. Scaling the results to the prototype, the fluorescence values are concentrations in ppb resulting from an injection of 100 metric tons (10^5 kilograms) of a contaminant.

Test Results

29. Figures 5 and 6 show plots of peak values (regardless of the depth at which the peak occurred) of C/m_d at each station along Nanticoke River for each tide sampled. The plots in Figure 5 show profiles of samples taken at slack before flood while Figure 6 shows slack before ebb. Figure 7 shows sta MH-1 (Marshyhope Creek) concentrations plotted versus time in tidal cycles. Dye concentrations from hourly samples at sta N-3A and N-3B during tide 13 are shown in Figure 8.

30. As can be seen from the figures, peak concentrations in the river tend to decrease with successive tidal cycles with a net transport of dye mass proceeding slowly downstream.

31. The farthest upstream intrusion occurred at sta N-6 (Seaford) after 43 tidal cycles. At that time, a value of 66 ppb/g was observed. This represents approximately 1 percent of the peak concentration (6,964 ppb/g) observed near the injection point during the third tidal cycle.

32. The arrival of the dye at the most downstream sampling location (sta N-1, near the mouth of the Nanticoke River) occurred between slack before flood of cycle 40 and slack before ebb of cycle 43. The first recorded value of 25 ppb/g (which reoccurred periodically throughout the remainder of the test) represents less than 1 percent of the peak 6,964 ppb/g concentration observed near the contamination point on the third tidal cycle.

33. Between tidal cycles 3 and 58, the dye concentration at

11

Sharptown (sta N-4) decreased appreciably. The 489 ppb/g concentration observed on tidal cycle 58 represents 7 percent of the peak concentration observed on tidal cycle 3.

Analysis

34. Pertinent to the question of contaminant spread are: (a) the rate at which the pollutant moves downstream, (b) the rate at which the peak concentration decays, and (c) the rate at which the plume spreads with respect to its center of mass.

35. To address these parameters, a third order polynomial was fit to each of the sets of synoptic slack-water fluorescence values (points outside the plume were ignored). From the resulting equations one can calculate the movement of the location of the peak, the decay of the peak with time, and the spread.

36. Figure 9 shows the location of peak fluorescence at the designated slack water. A linear regression yields a downstream velocity of 0.41 miles per day for slack before flood peaks and 0.29 miles per day for slack before ebb peaks.

37. Figure 10a shows the change of peak fluorescence with time.

38. "Spread" is defined as the longitudinal extent of polluted water with concentrations exceeding $1/e$ of peak concentration (e = 2.718). Figure 10b shows the increase of spread with time.

1.

PART IV: DISCUSSION

39. As mentioned previously, the boundary conditions in the
Nanticoke River and Chesapeake Bay can have an effect on the dispersion
of dye. Should a higher freshwater discharge occur on the Nanticoke
River and/or Marshyhope Creek, one could expect faster flushing toward
the bar with smaller concentrations observed upstream as compared with
the results for the conditions tested. Conversely, if lower freshwater
discharges occur, one could expect a slower flushing rate with higher
concentrations upstream.

40. The tidal condition at the time of injection can affect the
dispersion of dye. Spring tides would tend to increase dispersion in
upstream and downstream directions; neap tides would decrease this
amount of dispersion. The time of injection within a single tidal cycle
can also affect the dispersion. If injection occurs on a slack before
flood, the concentrations upstream will be larger than if injection
occurred on a slack before ebb.

41. The density and solubility of a particular contaminant can
have an effect on its dispersion in the system. A contaminant that
settles on the bottom will disperse at a rate different to one that
floats on the surface or one that mixes in the water column. The
physical properties of the particular contaminant should be considered
prior to applying these results to any given chemical spill.

Table 1

Boundary Conditions

Tides	Ocean	C&D Canal
Range, ft	2.6	Not operating
Amplitude, ft	1.3	Not operating
Plane, ft	0.0	Not operating
Source salinity, ppt	32.5	Not operating

Freshwater inflow:

Inflow No.	Tributary	Discharge, cfs
1	Nansemond R.	676
2	Chickahominy R.	289
3	Appomattox R.	967
4	James R.	7,249
5	York R.	2,659
6	Rappahannock R.	2,842
7	Wicomico R.	412
8	Occoquan Cr.	2,370
9	Anacostia R.	582
10	Potomac R.	7,699
11	Patuxent R.	881
12	Severn R.	231
13	Patapsco R.	613
14	Gunpowder R.	802
15	Susquehanna R.	37,217
16	Bohemia R.	386
17	Chester R.	502
18	Wye R.	190
19	Choptank R.	1,216
20	Nanticoke R.	403
20M	Marshyhope Cr.	249
20Q	Quantico Cr. (sums adjacent basins)	196
21	Pocomoke R.	1,369

Total discharge in bay 70,000 cfs

Table 2

Sampling Stations and Sampling Depths

Station	Water Depth ft	Sampling Depth ft below msl
N-1	27	4, 12, 24
N-1AW	13	2, 11
N-1AE	10	5
N-2	12	4, 11
N-2A	19.5	2, 18
N-2B	40	2, 20, 38
N-3	26.5	2, 13, 24
N-3A	29	2, 15, 27
N-3B	21.5	2, 11, 19
N-4	19	2, 17
N-4A*	18	Mid
N-5	14	2, 12
N-6	15	8
MH-1	9	5

* N-4A was added after tide 5. Sampling was
manual with pipette.

Table 3

Dye Fluorescence in Units of ppb per gram of Pure Dye Injected

												Tidal Cycle											
Station	Depth ft	3 SBE	5 SBF	8 SBE	10 SBF	15 SBF	18 SBE	20 SBF	23 SBE	25 SBF	28 SBE	30 SBF	33 SBE	35 SBF	38 SBE	40 SBF	43 SBE	45 SBF	48 SBE	50 SBF	53 SBE	55 SBF	58 SBE
N-1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	8	0	17	8	25	25
	12	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8	8	17	0	25	0	17	25
	24	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8	8	17	0	25	0	0	8
N-1AW	2	0	0	0	0	0	0	0	0	0	0	17	17	33	33	50	66	83	91	116	83	124	108
	11	0	0	0	0	0	0	0	0	0	0	17	25	33	25	50	33	91	66	116	66	124	83
N-1AF	5	0	0	—	0	0	0	0	0	0	0	25	0	33	25	41	33	83	50	99	50	124	83
N-2	4	0	0	0	0	0	0	33	8	41	25	83	66	141	91	190	132	257	141	290	182	323	207
	12	0	0	0	0	0	0	33	8	33	8	50	33	108	58	116	91	190	99	190	132	224	141
N-2A	2	0	0	0	0	58	50	190	133	406	257	431	389	596	464	687	530	787	513	770	580	770	662
	18	0	0	0	0	8	17	41	58	141	116	240	207	331	282	406	356	472	397	513	455	538	497
N-2B	2	0	0	0	33	232	99	530	240	787	356	1035	522	1168	662	1275	704	1234	720	1192	720	1151	745
	20	0	0	0	0	132	50	373	141	596	265	778	389	944	505	1035	530	1052	571	1043	629	1018	654
	38	0	0	0	0	124	41	323	124	522	232	745	356	845	472	977	530	1027	580	1010	629	969	638
N-3	2	0	0	0	364	1018	472	1590	770	1913	1052	2012	1225	2029	1350	1996	1292	1573	1234	1573	1225	1391	1143
	13	0	0	0	224	820	315	1350	604	1664	833	1888	1092	1904	1159	1904	1168	1623	1159	1590	1168	1391	1085
	24	0	0	0	124	580	406	985	571	1308	820	1606	1003	1689	1143	1689	1184	1557	1176	1443	1151	1325	1101
N-3A	2	0	174	75	1490	2459	1308	2948	1656	2360	1904	2550	1937	2443	1987	2123	1707	1789	1697	1540	1515	1333	1275
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N-3B	2	0	4090	869	5324	4860	2843	4197	2981	1395	2398	1734	1617	1987	1701	1593	1729	1209	1680	1010	1399	778	1234
	11	0	3105	523	5059	4819	2832	4032	2955	1271	2595	2641	2617	2079	2601	1731	1946	1292	1689	1043	1432	836	1209
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			1162	4929	713	6647	4736	3456					1888				119	683	770	447	571	323	464
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Table 4

Dye Fluorescence in Units of ppb per gram of Pure Dye Injected

for Hourly Samples During Tide 13

Tidal Hour*	Sta N-3A, Depth in ft			Sta N-3B, Depth in ft		
	2	15	27	2	11	19
1	646	422	373	2169	2194	2062
2	820	431	381	2418	2269	2062
3	828	638	588	2757	2824	2683
4	1548	803	936	4248	3676	3320
5	1466	1035	1317	4297	4446	4364
6	1913	1134	1018	4960	4976	4885
7	2260	1432	1201	5125	5175	5010
8	2136	1350	1018	5332	5200	4894
9	1764	1225	1027	5059	4894	4529
10	1184	1035	969	4032	4148	4041
11	820	803	795	3445	3594	3560
12	687	629	604	2650	2757	2799
12.42	671	497	447	2410	2434	2352

* Hour 0 = SBF at Vienna.
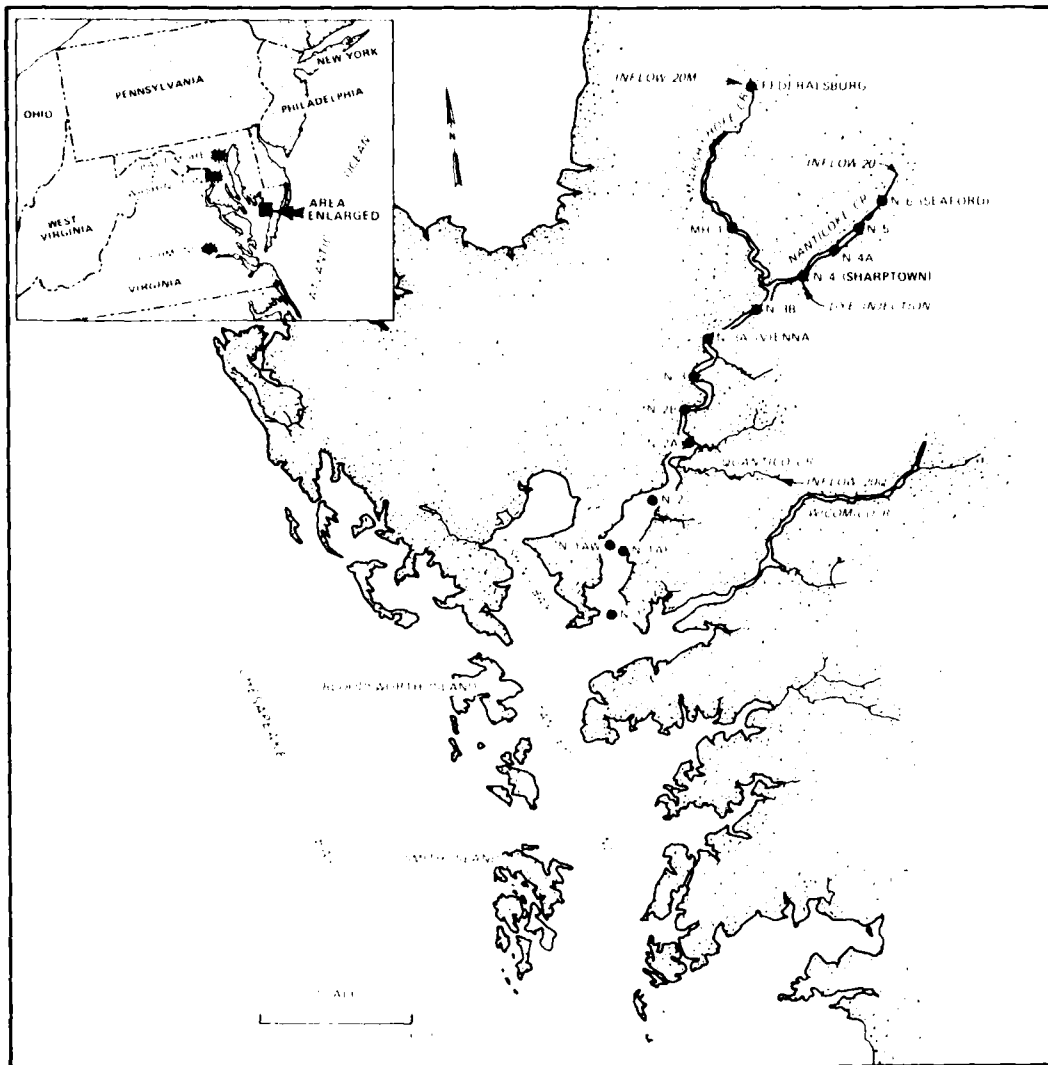
Figure 1. Location map showing sampling stations and
dye injection point on Nanticoke River
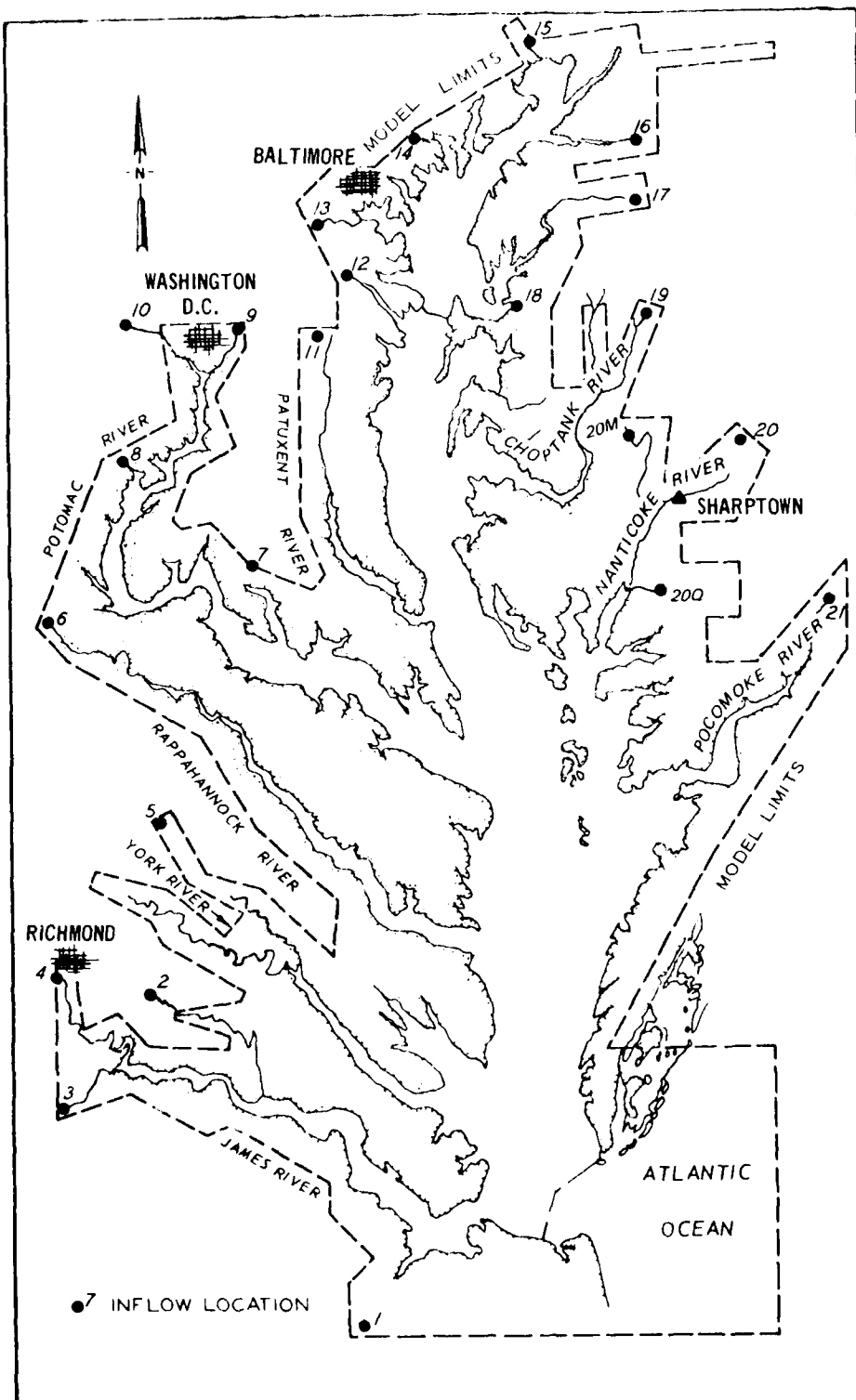
Figure 2. Model limits map and location of
freshwater inflows
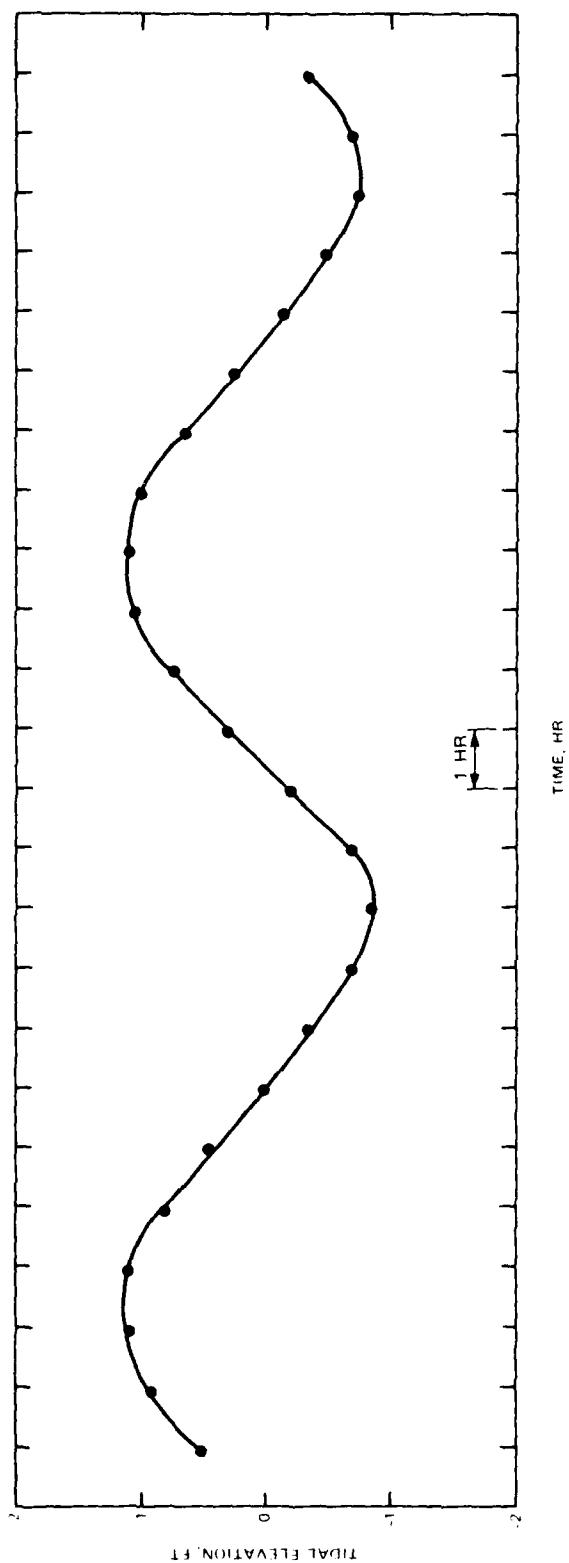
Figure 3. Tidal elevation at Vienna (N-3A)
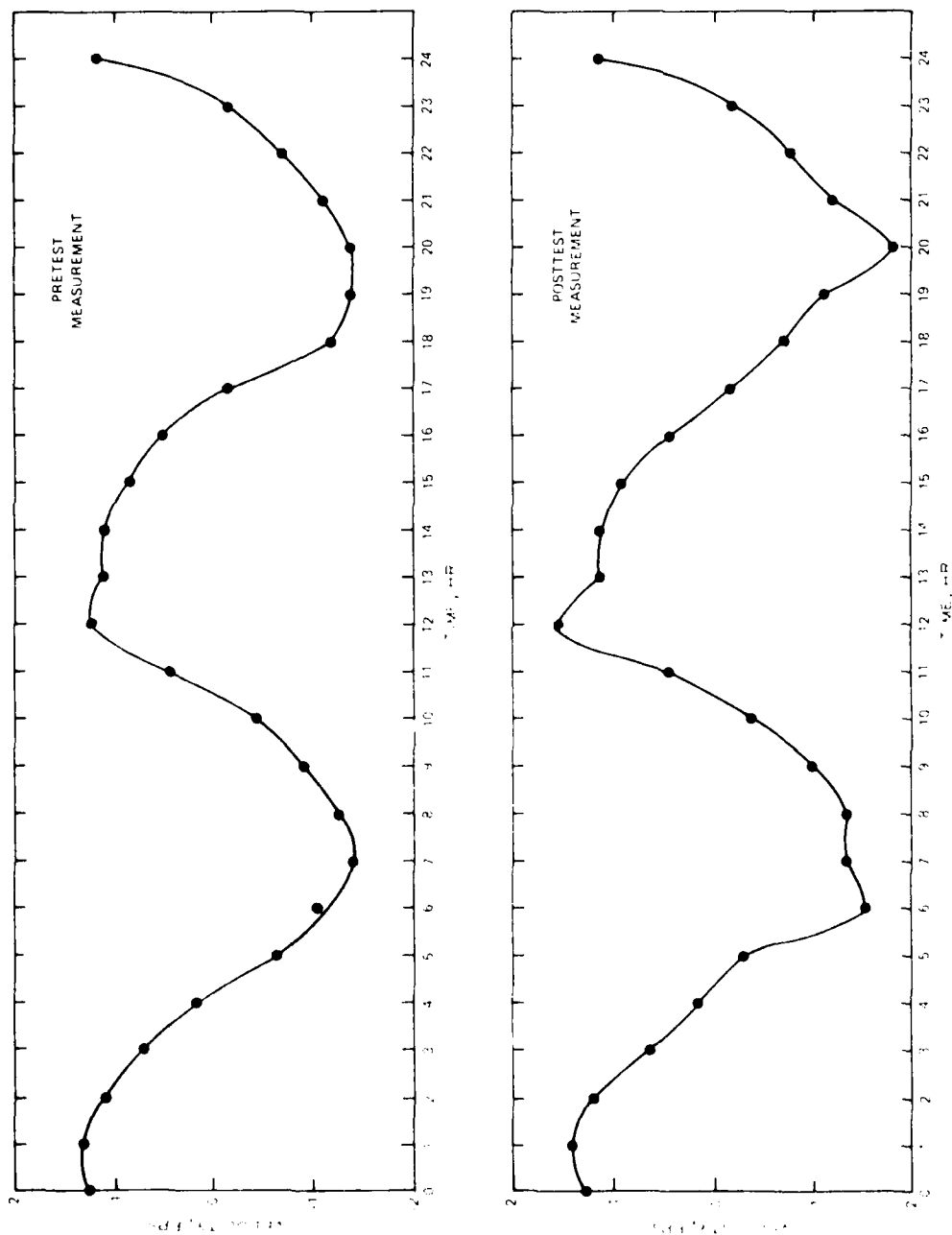
Figure 4. Tidal velocity at N-3. Positive is in the flood direction
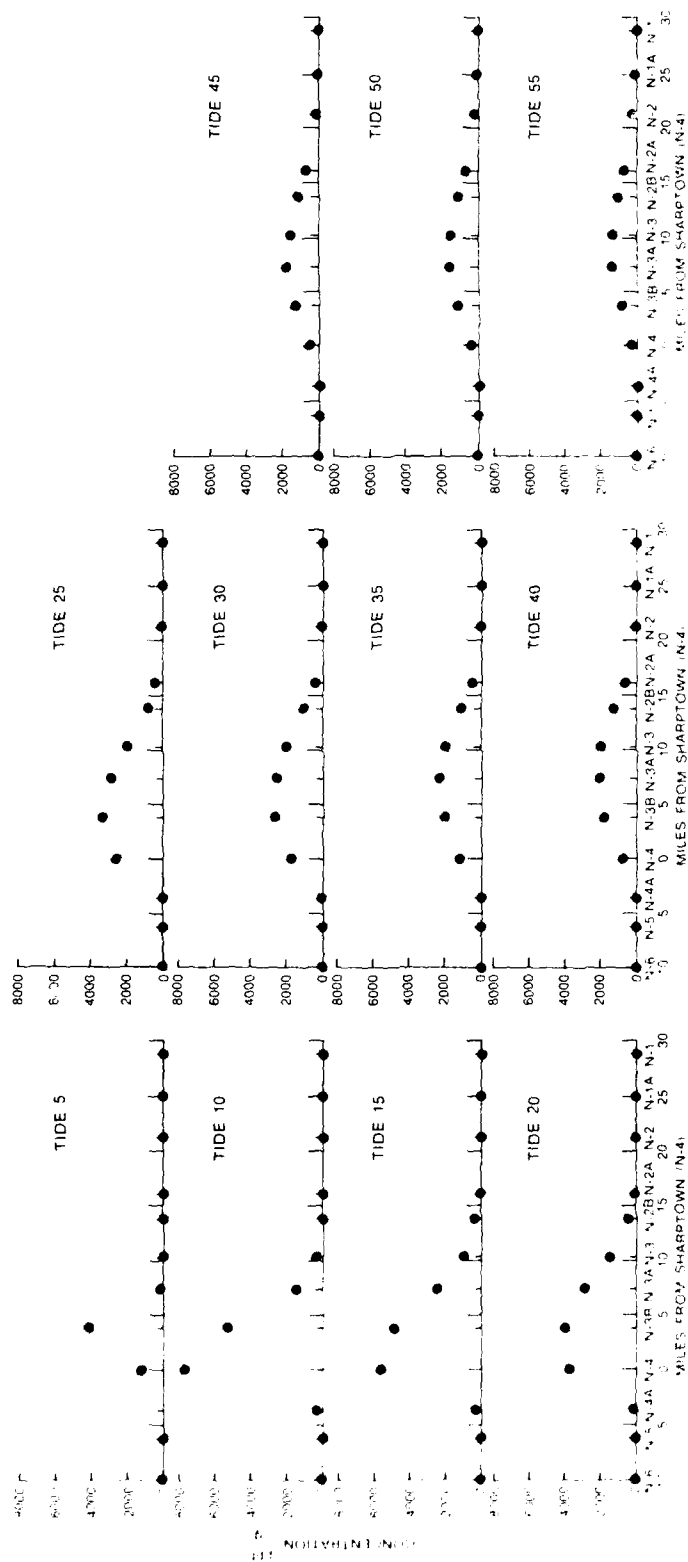
Figure 5. Dye fluorescence values (ppb per gram of dye injected) for samples taken at slack before flood. Plotted values are peak values for the designated stations regardless of where the values occurred in the vertical
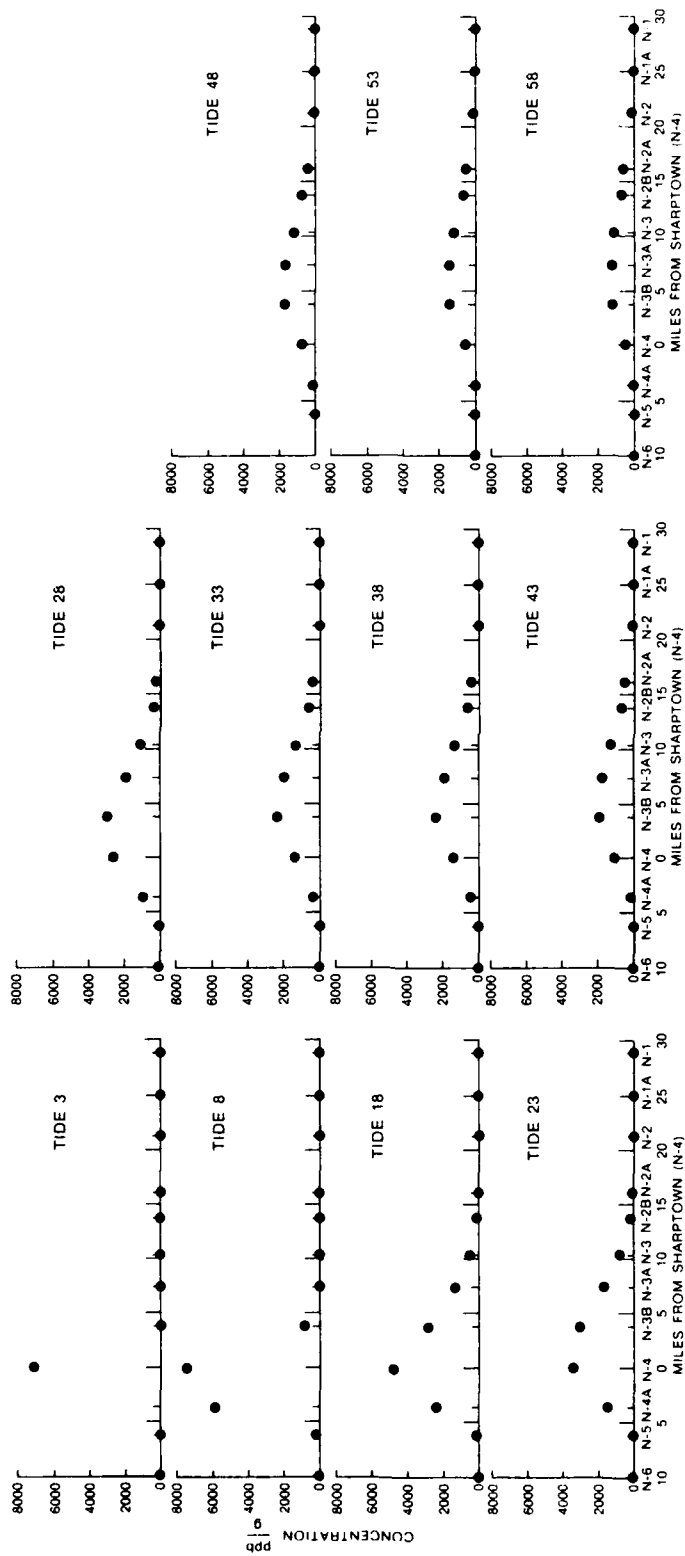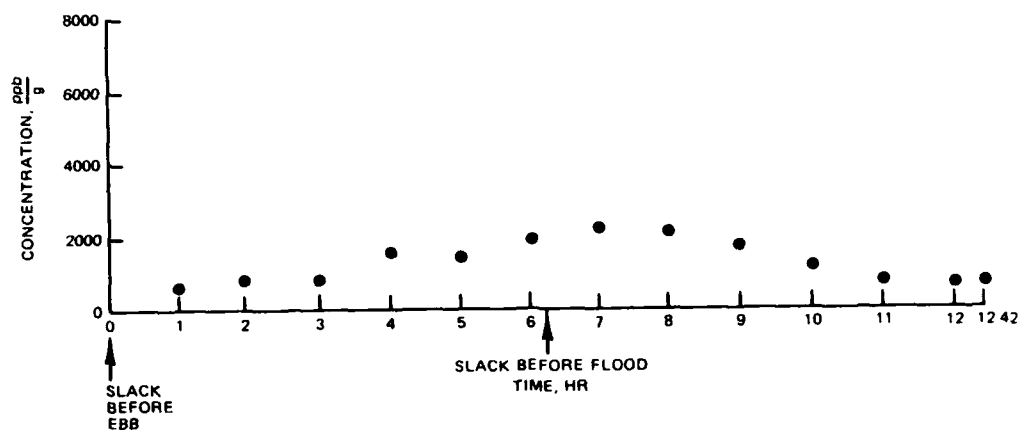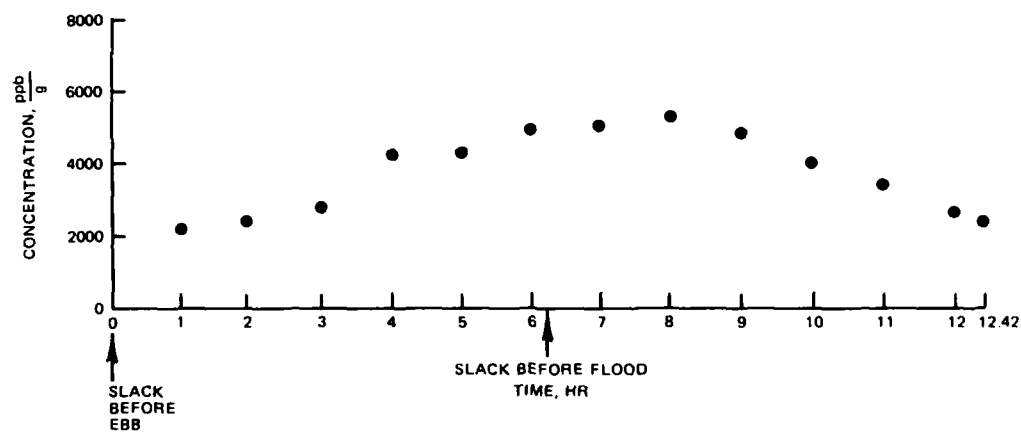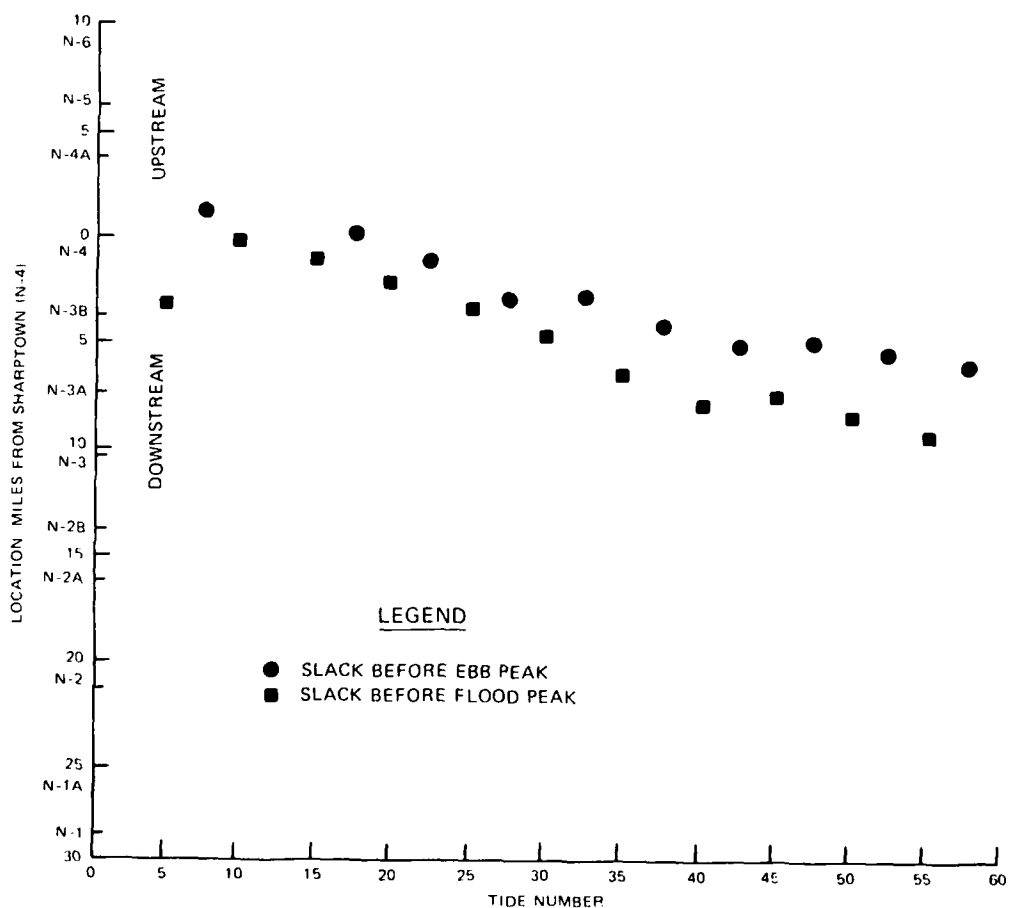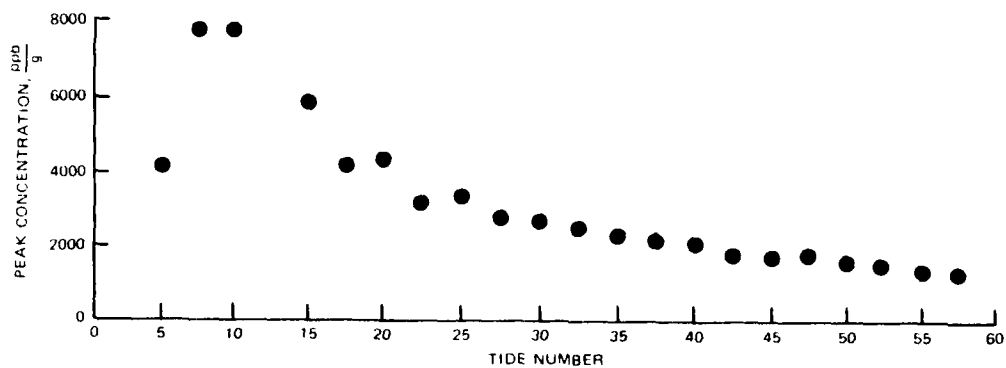
Figure 6. Dye fluorescence values (ppb per gram of dye injected) for samples taken at slack before ebb. Plotted values are peak values for the designated stations regardless of where the values occurred in the vertical
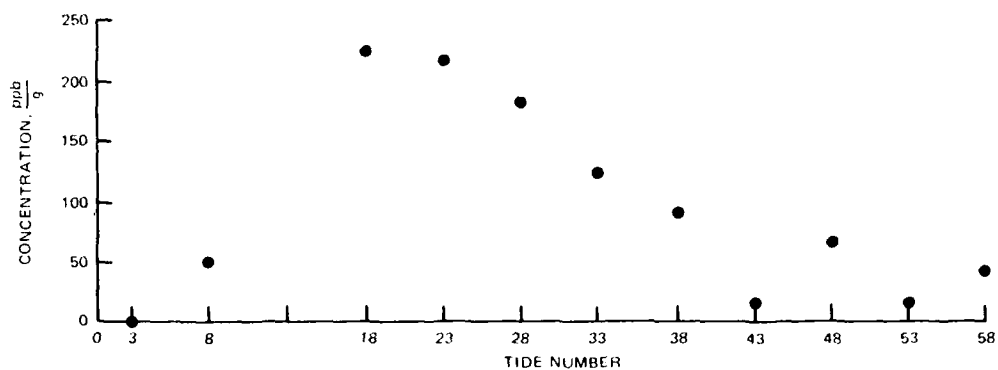
a. Slack before ebb
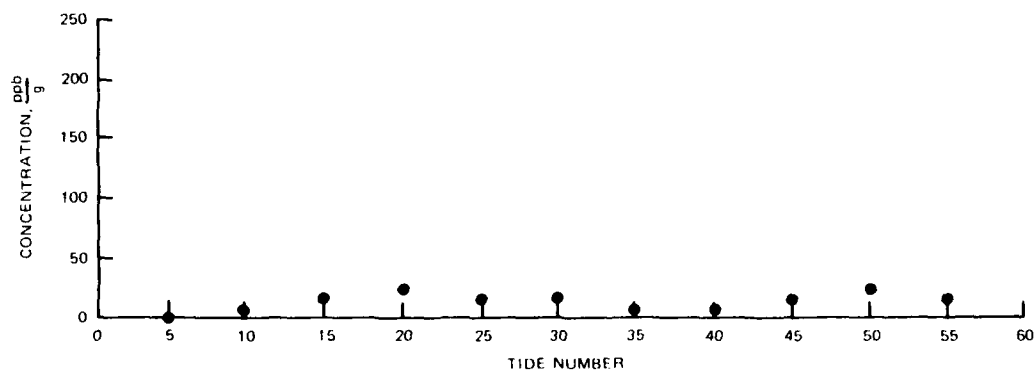
b. Slack before flood

Figure 7. Dye fluorescence values (ppb per gram of dye injected) for samples taken on Marshyhope Creek (MH-1) at the designated times

a. Tide 13 Sta N-3A

b. Tide 13 Sta N-3B

Figure 8. Dye fluorescence values (ppb per gram of dye injected) for
hourly samples taken during tide 13. Plotted values are peak values
for the designated station regardless of where the values occurred in
the vertical

Figure 9. Location of slack-water peak fluorescence values calculated from polynomial fit

a. PEAK FLUORESCENCE (ppb PER GRAM OF DYE INJECTED) IN THE PLUME
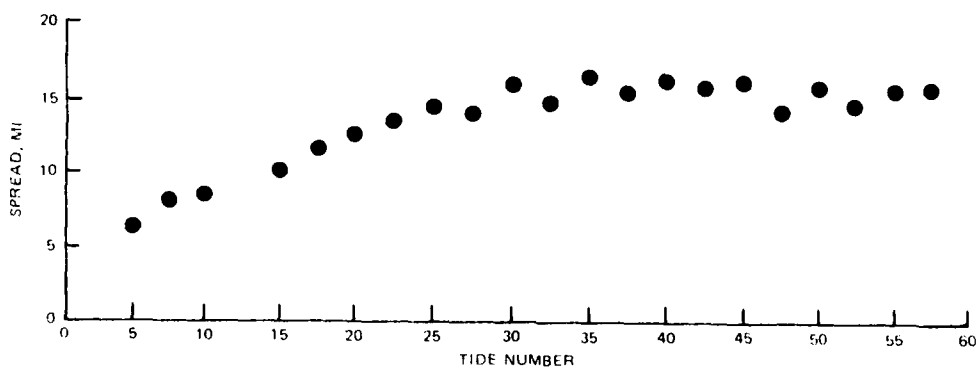
b. LONGITUDINAL EXTENT (SPREAD) OF FLUORESCENCE EXCEEDING 1/e OF PEAK VALUE

Figure 10. Time-histories calculated from polynomial fit

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